4

The Quaternary history of far eastern rainforests

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4.1 INTRODUCTION

4.1.1 Present setting

This region differs from those supporting tropical rainforest in other parts of the world in that it is less continental and geologically much more dynamic. It incorporates some major pieces of continental plate, but its center—the so-called "Maritime Continent" (Ramage, 1968)—is largely a complex interaction zone between the Asian and Australian Plates resulting from the continued movement of the Australian Plate into Southeast Asia (Metcalfe, 2002). The effects of tectonic and volcanic activity have resulted in mountain uplift, particularly in New Guinea, and formation of the volcanic island chain of Indonesia. Vulcanicity also occurs out into the Pacific beyond the "andesite line" where most "high" islands are volcanic and most "low" islands are coral islands developed on sunken volcanoes.

The extensive areas of continental shelf—particularly the Sunda and Sahul Shelves—but including the shelves along the east coast of northern Australia and around the South China Sea, combined with the impact of the Indonesian throughflow that restricts the movement of warm water from the Pacific to the Indian Ocean, have resulted in the highest sea surface temperatures on Earth in the form of the West Pacific Warm Pool. The enhanced convective activity associated with the warm pool results in high rainfall through much of the year in the heart of the Maritime Continent and dominance of the vegetation by evergreen rainforest. The area also provides the major source of heat release that drives the East Asian–Australasian summer monsoon system reflected in the strong summer rainfall patterns beyond the Intertropical Convergence Zone in each hemisphere, and resulting in the occurrence of seasonal, raingreen or "monsoon" semi-evergreen to deciduous rainforest over much of continental Southeast Asia and the very north of Australia (Figure 4.1). Additional influences on rainforest distribution are the warm northerly and southerly currents

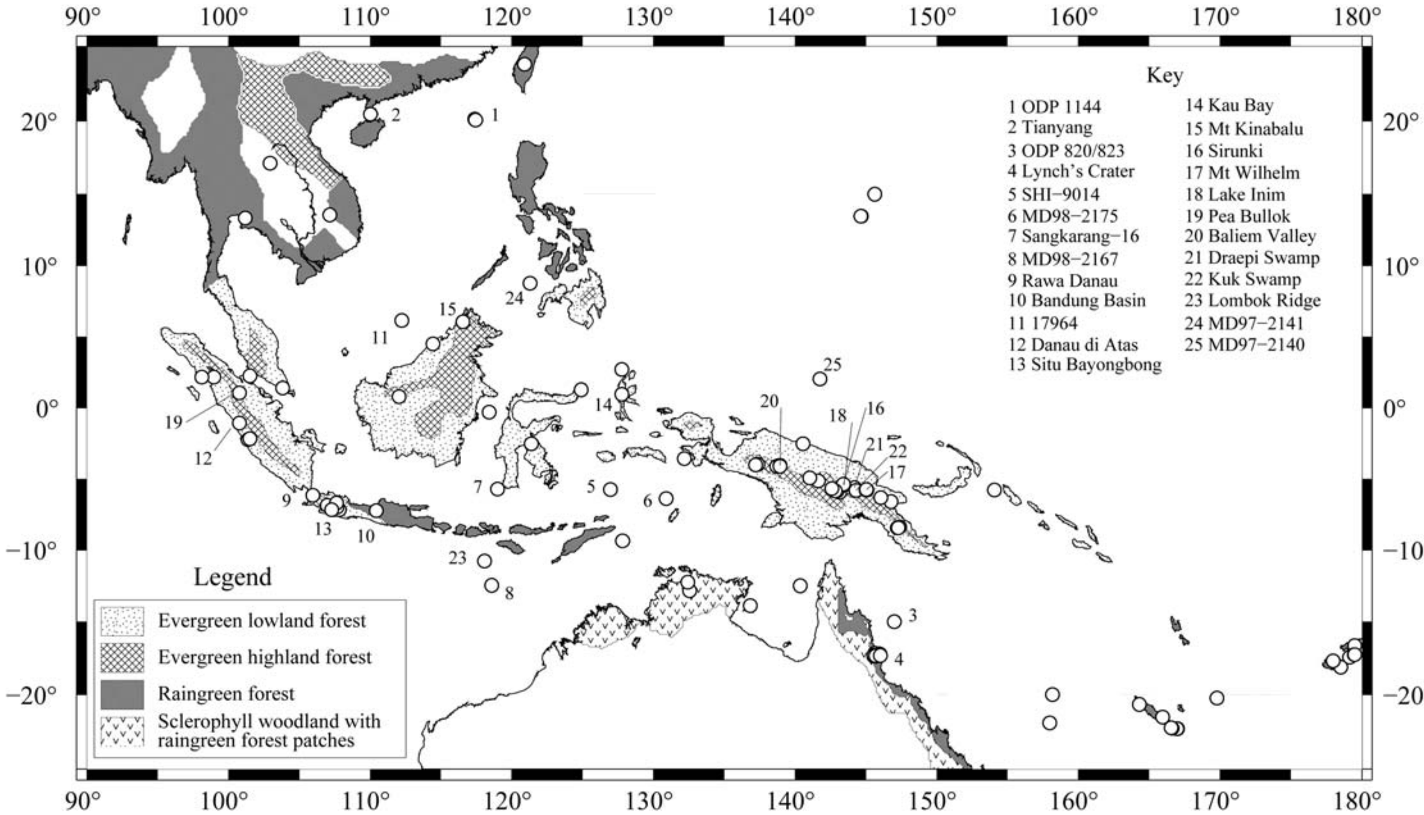

Figure 4.1. Distribution of rainforest vegetation in the far east and pollen-analyzed sites covering at least the last 6,000 years. Rainforest types have been simplified from distributions and descriptions of communities identified by Fedorova *et al.* (1993, 1994).

emanating from the Pacific equatorial current that, in combination with the southeast and northeast trade winds from the Pacific, result in the production of high orographic rainfall and associated rainforest along mountainous eastern coastal areas of Southeast Asia and Australia.

Most of the region is subjected to high interannual rainfall variability that is also, to a large degree, a product of its particular geography and the dynamics of oceanic and atmospheric circulation systems. The energy provided by convective activity within the Maritime Continent is the major contributor to the operation of the east–west Walker circulation that breaks down periodically, resulting in the movement of the warm water banked up against the Indonesian throughflow eastwards and resulting in a substantial reduction in precipitation from all sources over most of the region. These El Niño phases of the so-called "El Niño–Southern Oscillation" (ENSO)—that have also been linked to a weakening of the monsoon (Soman and Slingo, 1997)—can cause severe droughts and fires, even within rainforest, especially where there is disturbance from human activity.

Although tropical influences dominate the climate of the region, the Tibetan Plateau is important in creating a strong winter monsoon influence. The height and extent of this plateau results in the production of cool dry air that exacerbates seasonal contrasts in the northern part of the region and has a push effect on summer monsoon development in the southern hemisphere.

4.1.2 Nature of the evidence

Most of the evidence for past vegetation and climate from the region is derived from palynological studies. Perceived problems of pollen analysis in the lowland tropics—due to the richness of the flora, dominance of effective animal pollination, and lack of strong winds within the core area—resulted in most early research being focused on highland communities (Flenley, 1979). In these per-humid areas, a major interest has been and continues to be on altitudinal variation in the changing position and composition of montane rainforest and alpine zones in relation to global climate influences. Studies have been restricted mainly to swamps and shallow lakes covering the latter part of the last glacial period and Holocene.

Ventures into the terrestrial lowlands have generally not proved particularly successful due not only to original perceptions but also to the dearth of continuous sediment sequences in both perennially and seasonally wet environments, and lack of differentiation of peatland, riparian and dryland forest communities in the extensive peatlands that are otherwise very suitable for pollen analysis. Notable exceptions are deep defined basins of volcanic origin that have revealed detailed records of both vegetation and climate change, sometimes covering long periods of time.

A major feature of the region—that has been exploited in recent years—is the maritime setting whereby ocean basins occur in close proximity to land areas. A number of sediment cores have provided long and fairly continuous regional records of vegetation and climate change, securely dated from associated oxygen isotope records. Nevertheless, none of these records yet covers the whole of the Quaternary and reliance is placed on geologically isolated glimpses of past environments for some indication of the nature of the early part of this period.

4.2 MODERN POLLEN SAMPLING

Some basis for interpretation of Quaternary palynological records is derived from examination of patterns and processes of modern pollen deposition recorded in pollen traps and surface sediments. Such sampling examines deposition both within the rainforest and outside the rainforest in lake, swamp, and marine environments used for reconstructions of vegetation history.

The first quantitative study of pollen deposition in rainforest was by Flenley (1973). In the lowland rainforest of Malaysia he found significant pollen influx (between 800 and 2,020 grains/cm^2/annum) and relatively high pollen diversity (60 to 62 taxa) although representation within taxa through time was very variable. Similar results were found by Kershaw and Strickland (1990) in a north Queensland rainforest. They also found, from a knowledge of the distribution of trees surrounding the traps, that two-thirds of the pollen could have been derived from within 30 m of the traps. An examination of traps situated less than 100 m outside rainforest, in a small crater lake on the Atherton Tableland in north Queensland, demonstrated an enormous reduction in pollen deposition and substantial sifting out of pollen of local producers (Kershaw and Hyland, 1975). Pollen influx values dropped to below 200 grains/cm^2/annum and spectra were dominated by a relatively small number of taxa with significant regional pollen dispersal. It was determined that there was about equal representation of pollen from above canopy and rainout components. Any trunk space component was small and the high degree of correspondence between trap assemblages and those derived from the topmost part of a sediment core from the lake (Kershaw, 1970) suggested also that there was little inwash of pollen, though this component may have been trapped by marginal swamp.

Despite the great variability of pollen deposition within rainforest, patterns of representation appear to reflect systematic vegetation variation on a regional scale. Numerical analysis of a number of surface litter samples from throughout the lowland and sub-montane forests of northeast Queensland (Kershaw, 1973; Kershaw and Bulman, 1994) revealed a similar pattern to floristic analysis of forest plots from which the samples were derived. Although there was little in common between taxon representation and abundance in the two groups, it suggested that pollen assemblages could be used to characterize the broad environmental features of the landscape, including the vegetation. A similar result was achieved with the use of percentages of only those taxa that had been identified from lake-trapping and existing fossil pollen records as regionally important. This finding indicated the potential for analysis of pollen diagrams from tropical rainforest in a similar manner to those from other vegetation types where variation in abundance of a small number of taxa provides the basis for interpretation. Bioclimatic estimates for such "common taxa" in northeastern Queensland (Moss and Kershaw, 2000) demonstrate their potential for quantitative paleoclimatic reconstruction (Figure 4.2). The presence of numerous other taxa can allow refinement of interpretation (Kershaw and Nix, 1989) although insufficient pollen may be present in samples to allow counts of a sufficient size to demonstrate presence or absence in potential source vegetation. Figure 4.2 also demonstrates the degree of penetration into rainforest of pollen from the dominants of surrounding sclerophyll vegetation, *Eucalyptus* and *Casuarina*, that have generally wider pollen dispersal than rainforest taxa.

The heterogeneous nature of lowland tropical rainforest is an impediment to determination of the actual sources of "common" taxa and, therefore, their relative degree of dispersal. This complication is reduced at higher altitudes where widely dispersed taxa, many of which are clearly wind-pollinated, make up significant and identifiable components of the vegetation. The compilation of Flenley (1979) provides an excellent summary of variation in pollen representation along an altitudinal transect in New Guinea (Figure 4.3). Above the highly human-modified vegetation, clearly recognized by high values of Poaceae or *Casuarina*, the montane zones of oak and beech forest are dominated by pollen of their dominant taxa: *Lithocarpus/Castanopsis* and *Nothofagus*, respectively. Upper montane mixed forest is characterized by *Quintinia* while alpine vegetation is recognized by the only occurrences of "alpine pollen taxa". The bare ground on the mountain summit has a unique pollen signature that clearly identifies those taxa, *Nothofagus* and *Casuarina*, which have wide pollen dispersal. Flenley (1979) remarks on the tendency for pollen to be carried uphill and suggests it is due to the fact that pollen is released during the day when anabatic winds are active.

A much broader indication of pollen transport, including a potentially major water-transported component, is provided by recent analyses of suites of core-top pollen samples from the Indonesian–Australian region (van der Kaars, 2001; van der Kaars and De Deckker, 2003; van der Kaars, new data) and the South China Sea (Sun *et al.*, 1999). Isopolls interpolated from samples along the steep precipitation gradient from east Indonesia to northwest Australia are shown for major pollen groupings based on a dryland pollen sum, excluding pteridophytes (Figure 4.4). This gradient is clearly reflected in the pollen with predominantly rainforest taxa including pteridophytes showing high values in the rainforested Indonesian region and then progressively declining relative to the predominantly sclerophyll taxa of Myrtaceae (attributable mainly to *Eucalyptus*) and Poaceae that dominate Australian vegetation. Compared with other pollen types, the pollen of rainforest angiosperms reflect most faithfully the distribution of rainforest. Rainforest conifers are much better represented than angiosperms considering their almost total restriction to montane forests, a feature no doubt due to obligate wind dispersal of pollen and greater opportunity for wind transport from higher altitudes. The major concentration of montane pollen types between Sulawesi and New Guinea reflects also the proximity to mountainous areas within the study area. Pteridophyte spores have a very similar distribution to the rainforest conifers and, although this pattern can be accounted for—to some degree—by the fact that they are most abundant in wet tropical and often montane forest, transport is facilitated also by water. The fact that percentages of pteridophytes are so much higher than those of pollen is probably the result of effective water transport.

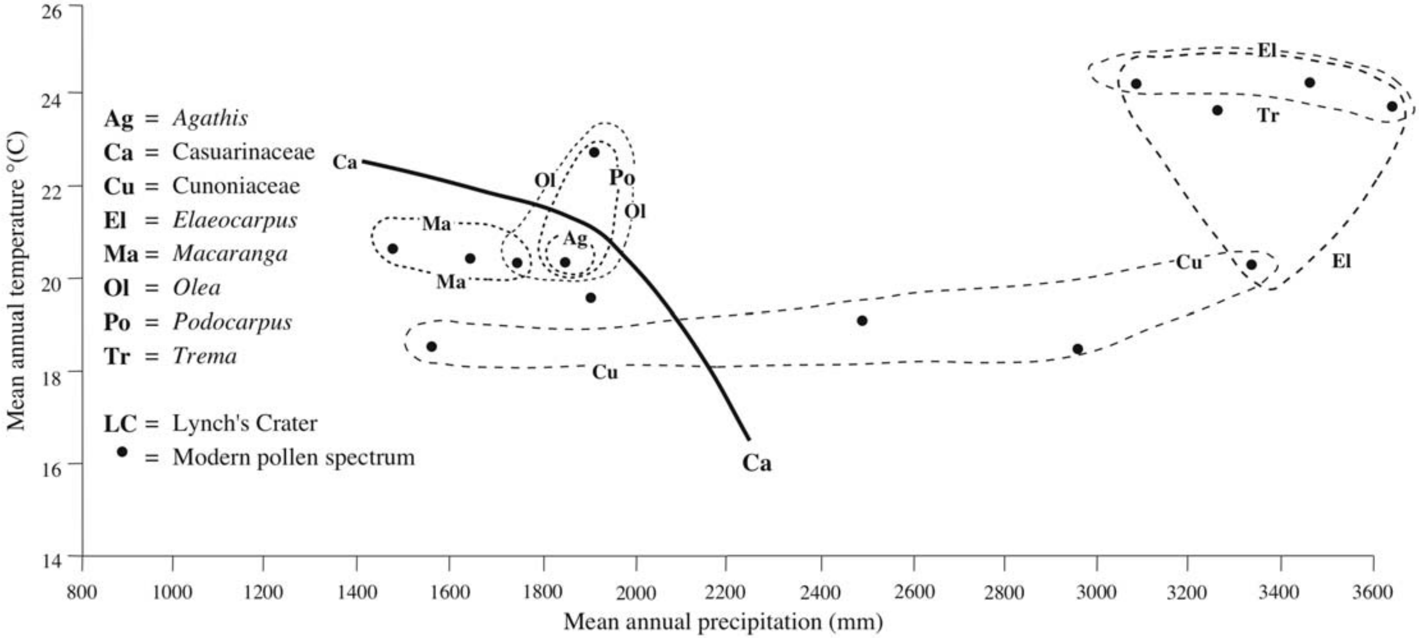

Figure 4.2. Climatic ranges for highest representation of major rainforest taxa in relation to bioclimatic estimates for modern pollen samples from northeast Queensland rainforests. The extent of penetration of high values for the sclerophyll woodland taxon Casuarinaceae is also shown (adapted from Moss and Kershaw, 2000).

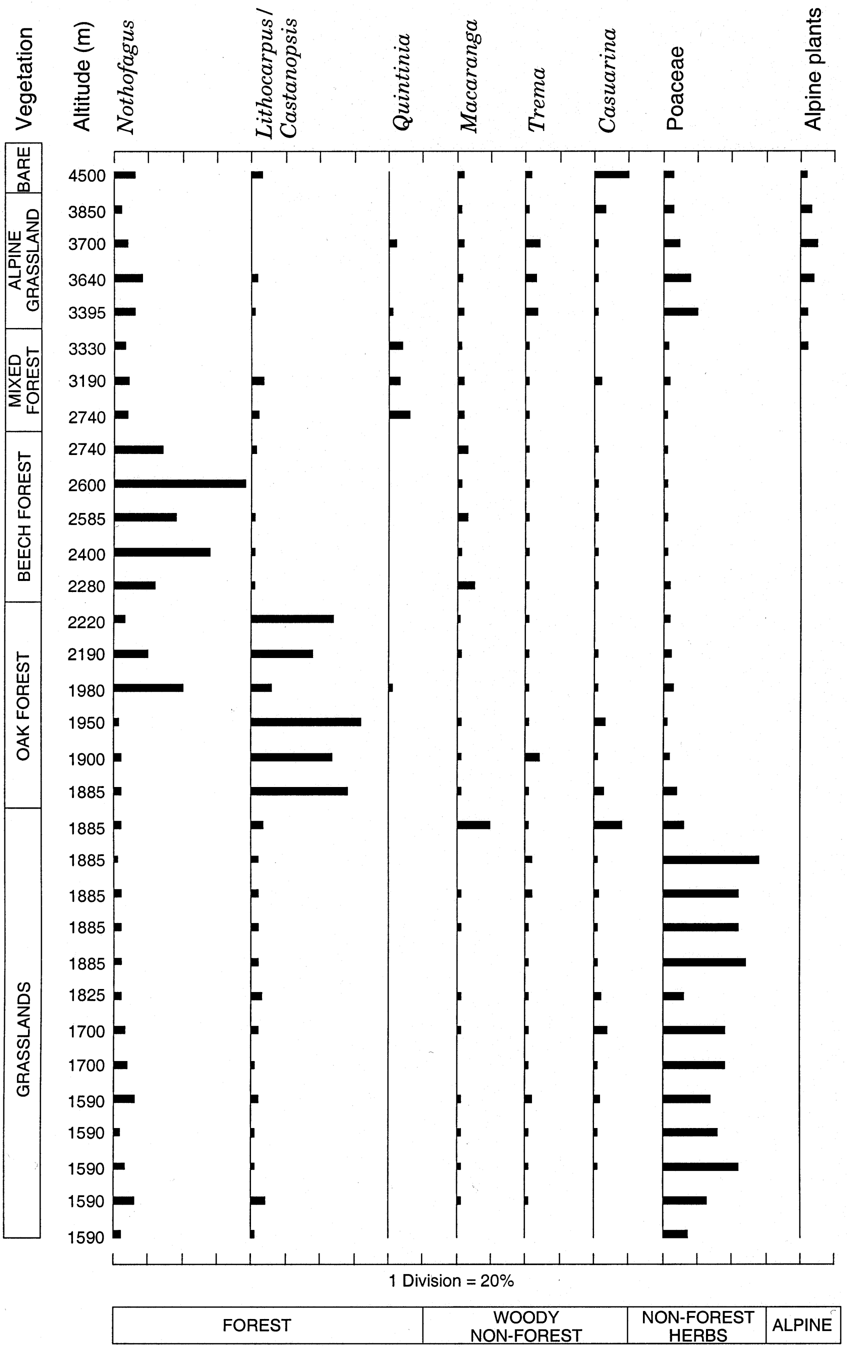

Figure 4.3. Representation of major pollen taxa in relation to vegetation along an altitudinal surface sample transect in Papua–New Guinea (modified from Flenley, 1973).

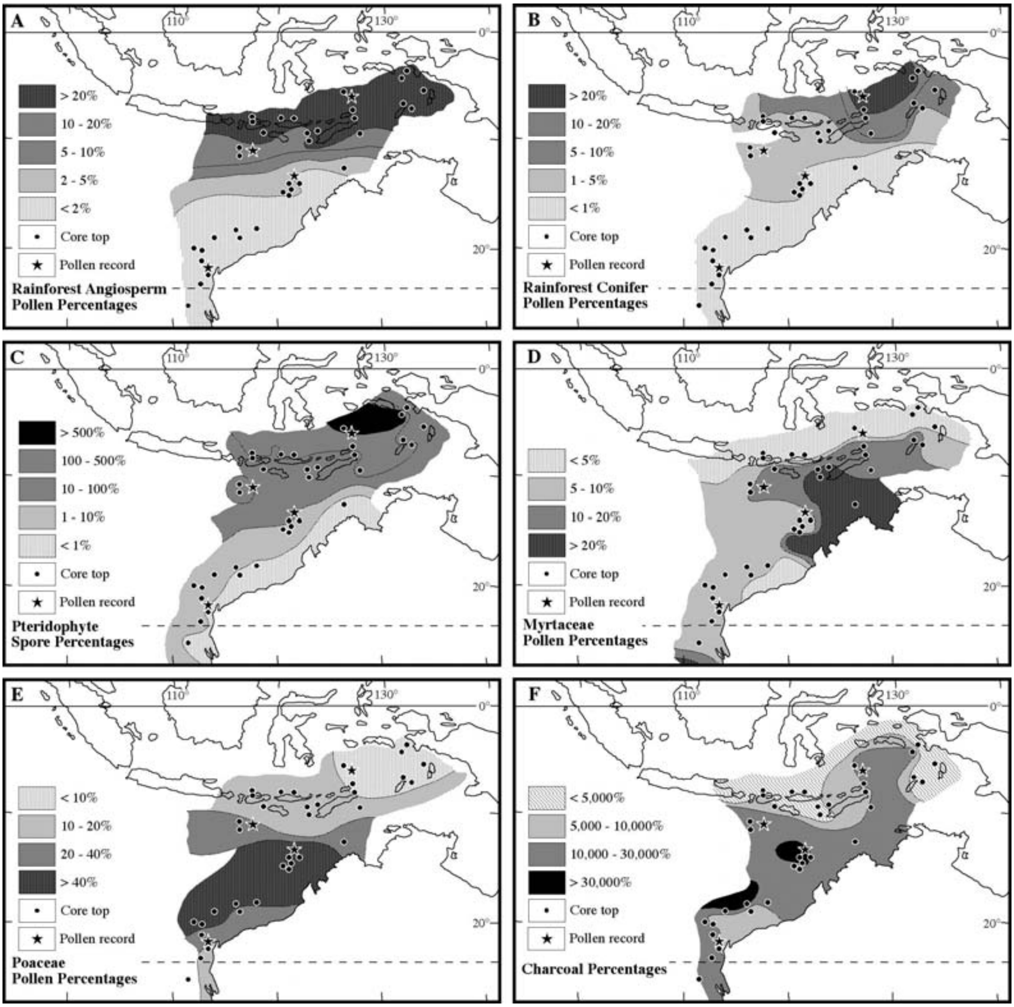

Figure 4.4. Relative abundance of major pollen groups, taxa, and charcoal derived from core-top samples in the northwestern Australian–southern Indonesian region based on a pollen sum of total dryland pollen excluding pteridophytes. Data from van der Kaars and De Deckker (2003) and van der Kaars (2001).

In contrast to pollen—that generally reflects the regional representation of vegetation—charcoal, derived from the same samples, shows a less certain pattern, at least in percentage terms. It is very unlikely that fire activity is highest in the open ocean where charcoal values are highest. This clearly indicates that charcoal particles, on average, are transported farther than pollen. However, it is clear from a general decline northwards that charcoal is, as expected, derived mainly from Australia. The reduction in charcoal percentages in the very northwest of Australia may be realistic as, within this very dry area, a lack of fuel would allow only the occasional burn.

The South China Sea shows largely an inversion of the southern hemisphere pattern (Figure 4.5). Here, tropical rainforest angiosperm pollen is derived largely from the equatorial humid region centred on Borneo and decreases northwards relative to *Pinus* which may be regarded as the equivalent of Australian sclerophyllous trees, in its dominance of drier and more seasonal open forests that cover large areas of Peninsular Southeast Asia and more subtropical forests of southern China. The much higher values of *Pinus* are considered to result from the influence of the strong northerly winter monsoons that blow while *Pinus* trees are still in cone, in addition to the high production and dispersal rates of its pollen (Sun *et al.*, 1999). The rainforest gymnosperms—represented in Figure 4.5 by their most conspicuous genus,

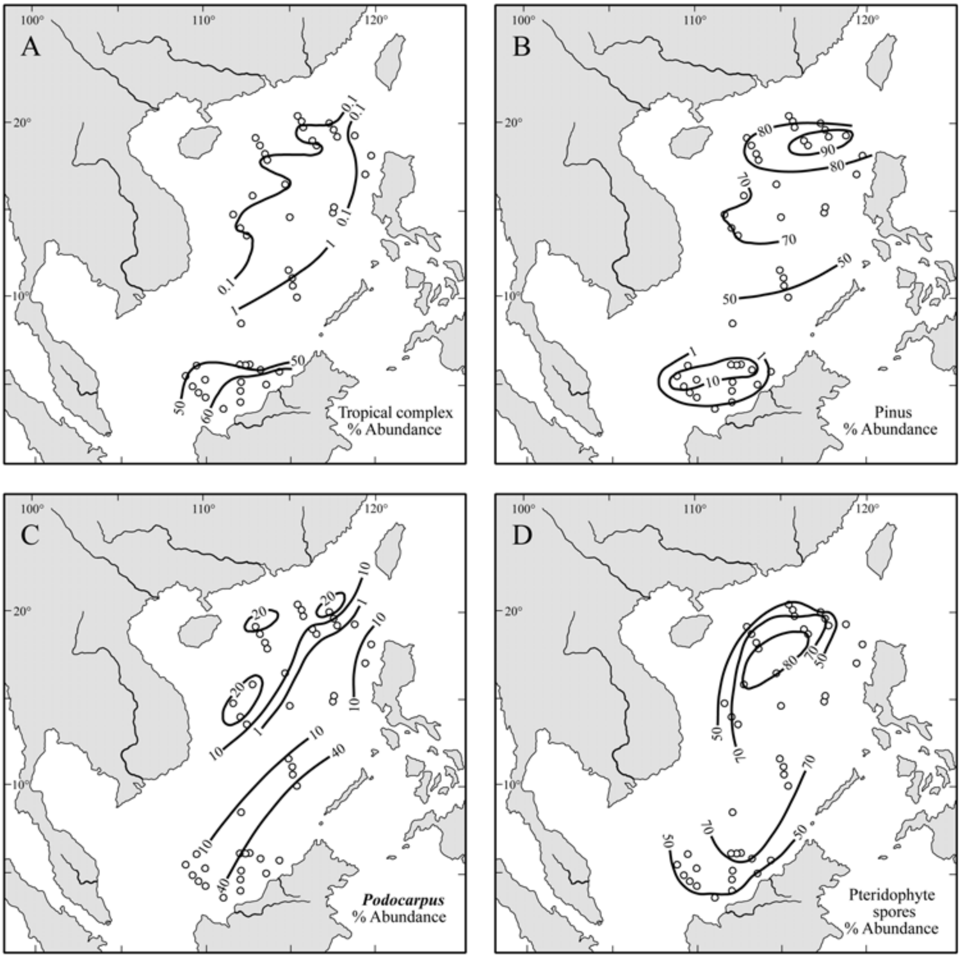

Figure 4.5. Relative abundance of major pollen groups and taxa derived from core-top samples in the South China Sea based on a pollen sum of total dryland pollen excluding pteridophyes. Adapted from Sun *et al.* (1999).

Podocarpus—clearly show much broader pollen dispersal than the angiosperms and sources in both the equatorial tropics and mountains in southern China. Pteridophyte values, when consideration is given to the different basis for calculation of the pollen sum, are similar to those in southern waters, but are demonstrably well dispersed with highest percentages towards the center of the basin. Although not illustrated, mangroves in both data sets show highest values close to coastal locations with a substantial fall away from the coast.

4.3 REGIONAL TAXON REPRESENTATION

Some indications of those taxa that contribute to a regional picture of the vegetation within the tropical rainforest-dominated regions of Southeast Asia and Australia are shown in relation to major ecological groups in Table 4.1. The distinctions between the major taxonomic groups—between essentially evergreen or raingreen and winter deciduous trees, and between rainforest and open forest trees—are fairly clear but those between altitudinally defined rainforest groups are somewhat arbitrary due to the continuous nature of floristic variation, the influences of factors other than temperature on distribution, and the variety of terminologies used for vegetation description in different areas. With the "montane" conifers, for example, Morley (2000) questions the designation of *Podocarpus* and *Dacrydium* as indicative of high-altitude rainforest as they can occur in lowlands, particularly in association with low nutrient-status soils. The inclusion of New Caledonia with its ultra-mafic soils would result in an almost total breakdown of an altitudinal classification.

Despite the long period of isolation of the Australian and Southeast Asian continental plates (Morley, 2000) and apparent limited taxon exchange—apart from New Guinea, within the period of potential contact, the Late Miocene—there are major similarities between pollen floras from the different regions, at least at identified levels. This similarity is most evident with the lowland angiosperms. This group is large, usefully reflecting the floristic diversity of these forests, though low pollen taxonomic resolution disguises much variation in regional representation. Much of this diversity can be accounted for by the lack of dominant wind-dispersed taxa. Although many of the important families and genera in the forest are recognized, there are major biases in representation. For example, the dominant family in Southeast Asian lowland forests, Dipterocarpaceae, is very much under-represented in pollen spectra while the pollen of the dominant family in Australian rainforests, Lauraceae, is hardly recorded. Secondary or successional taxa—such as many Moraceae/Urticaceae, *Macaranga/Mallotus*, *Trema*, and *Celtis*—are, by contrast, over-represented.

The greater differentiation in montane and lower montane elements is due to refined identification of a more limited suite of taxa, many of which contain few species, as well as distinctive northern or southern origins. There is no evidence of taxa—such as *Engelhardia*, *Myrica*, *Altingia*, *Liquidambar*, *Lithocarpus/Castanopsis*, or *Quercus*—reaching Australia although a number have reached New Guinea, while *Dodonaea*, *Nothofagus*, *Quintinia*, and *Araucaria* have not expanded northwards into, or through the whole of, the Southeast Asian region. It is interesting that the southern

Table 4.1. Common pollen taxa of major ecological groups in the far east.

Major ecological groups	Common pollen taxa	China Sea region	Southern Indonesia	New Guinea	Northeast Queensland
Montane conifers	*Dacrycarpus*	×	×	×	
	Dacrydium	×	×	×	
	Podocarpus	×	×	×	×
	Phyllocladus	×	×	×	
Montane angiosperms	*Coprosma*			×	
	Dodonaea		×		(×)
	Drimys	×		×	×
	Engelhardia	×	×		
	Epacridaceae	×			×
	Ericaceae	×	×	×	
	Leptospermum	×			×
	Myrica	×			
	Myrsinaceae	×		×	×
	Nothofagus			×	
	Quintinia			×	×
Lower montane conifers	*Agathis* (Araucariaceae)			×	×
	Araucaria (Araucariaceae)				×
Lower montane angiosperms	*Altingia*	×			
	Cunoniaceae			×	×
	Hammamelidaceae	×			
	Liquidamber	×			
	Lithocarpus/Castanopsis	×	×		
	Quercus	×	×		
Lowland angiosperms	*Acalypha*	×		Insuf. data	×
	Anacardiaceae	×	×		×
	Barringtonia		×		
	Bischoffia		×		×
	Calamus		×		×
	Celastraceae	×			×
	Celtis	×	×		×
	Calophyllum		×		×
	Dipterocarpaceae		×		
	Elaeocarpaceae	×	×		×
	Euphorbiaceae	×	×		×
	Ilex	×	×		×
	Macaranga/Mallotus	×	×		×
	Melasomataceae	×			×
	Meliaceae	×	×		×
	Moraceae/Urticaceae	×	×		×

(*continued*)

Table 4.1 (*cont.*)

Major ecological groups	Common pollen taxa	China Sea region	Southern Indonesia	New Guinea	Northeast Queensland
Lowland angiosperms	Myrtaceae	×	×		×
	Nauclea		×		
	Oleaceae	×	×		×
	Palmae	×	×		×
	Proteaceae		×		×
	Rubiaceae	×	×		×
	Rutaceae	×	×		×
	Sapindaceae	×	×		×
	Sapotaceae	×	×		×
	Sterculiaceae				×
	Trema	×	×		×
Open forest (savanna)	*Casuarina*		×	×	×
	Eucalyptus		×	×	×
	Melaleuca		×	×	×
	Pinus	×			
Herbs	*Artemisia*	×			
	Cyperaceae	×	×	×	×
	Poaceae	×	×	×	×
Alpine herbs and shrubs	*Astelia*			×	
Pteridophytes		×	×	×	×
Winter deciduous forest		×			

podocarps have their lowest diversity in northeast Queensland despite the fact that they probably dispersed from the Australian region. *Dacrycarpus* and *Phyllocladus* did not arrive in Southeast Asia until the Plio-Pleistocene, but *Dacrydium* and *Podocarpus* have had a much longer residence (Morley, 2002). *Phyllocladus* has extended no further north than Borneo, so its pollen representation in the South China Sea region must derive from this source. *Nothofagus brassospora* has failed to cross into montane Southeast Asia and has also been lost from Australia. Indeed, percentages of *Nothofagus* pollen fall off rapidly with distance from New Guinea. The poor representation of *Nothofagus* pollen in marine sediments is perhaps unexpected considering its proposed high dispersal capacity (Flenley, 1979). Pollen of the open forest regional dominants of the northern and southern subtropics—*Pinus* and *Eucalyptus*/Casuarinaceae, respectively—hardly extend into the other hemisphere despite proposed continuity of monsoon influences across the equator. This pollen is probably explained by limited direct wind connections and the efficiency of pollen removal from the atmosphere within the everwet equatorial zone. Patterns for Casuarinaceae and *Eucalyptus* are regionally complicated: the former by the existence of several component species within rainforest in Southeast Asia and New Guinea, and the latter by problems in consistent separation from rainforest Myrtaceae and, less importantly, from the other major, myrtaceous, sclerophyll genus, *Melaleuca*.

There are no identifiable extratropical elements in pollen assemblages from the Australasian region. Both subtropical and warm temperate rainforest floras are essentially depauperate tropical floras, while sclerophyll elements have a recognizable pollen flora similar to that in the tropics. In contrast, assemblages from the South China Sea contain notable percentages of deciduous temperate taxa—as well as the temperate steppe taxon, *Artemisia*—and no doubt a temperate *Pinus* component transported, at the present day, by the winter monsoon.

Herbs other than *Artemisia* would have been derived mainly from the tropical savannas. However, some component would have been derived from anthropogenic grasslands and perhaps also—in the case of the Cyperaceae, in particular—from coastal rivers and swamps, although under natural conditions peat swamp forests and mangroves would have dominated many coastal communities. Rhizophoraceae is the most conspicuous mangrove taxon, and especially so in pollen assemblages. The percentages of pollen from mangroves fall off rapidly from the coast in marine assemblages.

No differentiation is made within the pteridophyte category that is composed largely of fern spores. It is clear from the surface samples that fern spores have highest values in wetter forests. They are derived mainly from tree ferns and epiphytes, with ground ferns becoming common in higher altitude forests and in some mangroves.

4.4 LONG-TERM PATTERNS OF CHANGE

The general composition and distribution of tropical rainforest was established well before the onset of the Quaternary period (Morley, 2000), with the only recognized major dispersal since this time being the expansion of *Phyllocladus*, probably from the New Guinea highlands into the highlands of the southern part of Southeast Asia.

There are only two records that cover much of the Quaternary period—one from the northern part of the South China Sea, and the other from the Coral Sea off northeastern Australia—and these necessarily provide the framework for establishment of temporal patterns of change during much of this period.

4.4.1 The South China Sea region

Sun *et al.* (2003) provide a near-continuous, high resolution (i.e., 820-year average time interval between samples) record from ODP Site 1144 (20°3″N, 117°25″E) taken from a water depth of 2,037 m equidistant from southern China, Taiwan, and the Philippines (Figures 4.1 and 4.6). The record covers marine isotope stages (MIS) 29 to 1 or the last 1.03 Myr. In terms of major ecological groups represented, there is little

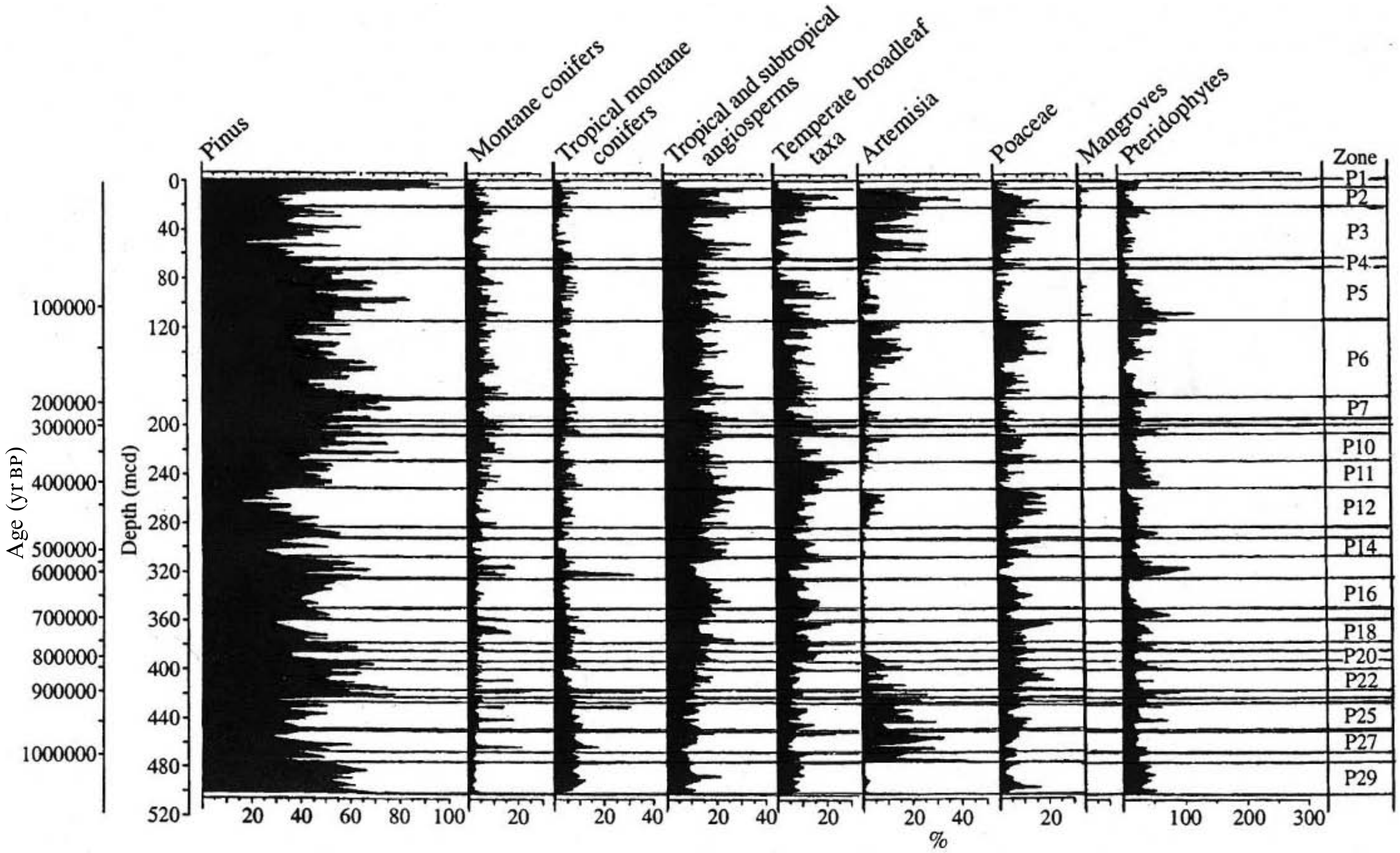

Figure 4.6. Relative abundance of major taxa and taxon groups in the pollen record from ODP Site 1144, South China Sea (after Sun *et al.*, 2003). All taxa are expressed as percentages of the dryland pollen sum, that excludes Pteridophyta and mangroves.

consistent change in representation and variability is generally lowest in the rainforest groups, tropical and lower montane (subtropical) taxa, montane conifers, and, to some degree, pteridophytes. There is some indication that lower altitude rainforest has generally expanded from about 600 kyr, after the Early–Middle Pleistocene transition, while there has been an overall reduction since this time in montane conifers. Throughout the record, the greatest variation is in the dominant groups: the herbs and *Pinus*, with the former showing highest values during the glacial periods and the latter during interglacials. It is proposed that some of this variation is a result of glacials being drier than interglacials, an interpretation supported by generally higher values of pteridophytes during interglacials. It is suggested by Sun *et al.* (2003), however, that it was not a simple replacement of herb vegetation by *Pinus*, but that herbs were largely derived from the exposed continental shelf and *Pinus* from more distant mountain areas. The substantial component of *Artemisia* at times within the herb component might suggest also that temperatures during glacial periods were much reduced, even at sea level. However, the very high values for *Artemisia* steppe vegetation during the Last Glacial Maximum are interpreted not in terms of climate but considered the result of a tectonically-induced broader continental shelf relating to an uplift of the Tibetan Plateau around 150 kyr. This interpretation seems inconsistent, though, with the presence of equally high values of *Artemisia* through much of the period from 1,000 to 900 kyr, where no expansion of the continental shelf area is inferred.

This overview of major pollen components in the ODP Site 1144 record masks some important changes that have taken place in the representation of tropical rainforest taxa over the last million years. From a separate portrayal of relative taxon abundance in relation to a lowland and montane tropical rainforest sum, Sun *et al.* (2003) identify three major periods. The earliest, before 900 kyr, is characterized by relatively high values for tropical montane taxa and *Altingia*, suggesting cool conditions, consistent with a climatic interpretation for the high *Artemisia* values. The period corresponds with minimum variation in the marine isotope record. Increased temperature is inferred for the subsequent period, 900 kyr to 355 kyr, where lowland taxa including Dipterocarpaceae, Celastraceae, *Macaranga*/*Mallotus*, and *Trema* were more conspicuous. This interpretation appears counter to that from the accompanying isotope record where generally lower temperatures may be inferred. From about 355 kyr, the submontane taxa *Quercus* and *Castanopsis* markedly increase their dominance. The abundance of these taxa in seasonal forests in southern China suggests that the climate was more seasonal as well as cooler. The period also marks the entry into and consistent representation of Moraceae, Oleaceae, and *Symplocos* in the pollen record as well as marked increases in Apocynaceae, Rubiaceae, Sapindaceae, and Sapotaceae, indicating a substantial change in the composition of lower altitude rainforest. The restriction of mangrove pollen to this period may seem surprising but could relate to the achievement of higher temperatures periodically with more pronounced glacial–interglacial cyclicity or to changes in coastal configuration. However, the marine isotope record indicates that the amplitude of glacial oscillations increased about 600 kyr, much before the onset of this period.

A pollen record from the lowland Tianyang volcanic basin of the Leizhou Peninsula on the northern coast of the South China Sea and at a similar latitude to ODP Site 1144 (Zheng and Lei, 1999) provides a useful terrestrial comparison of vegetation changes for the region to the marine core for the Late Quaternary period. OSL and radiocarbon dating combined with paleomagnetic analyses have allowed tentative correlation of the record with the marine isotope record over the last 400 kyr. In contrast to the marine record, the dominant pollen types are the evergreen oaks (*Quercus* and *Castanopsis*) that derive from the mountains surrounding the site. The fact that there is only low representation of lowland rainforest taxa, despite the fact that tropical semi-evergreen rainforest surrounds the site, supports the evidence for relatively low pollen production and dispersal from this vegetation formation within modern pollen studies. However, the much lower values for *Pinus* and pteridophytes—together with the fact that they tend to peak in glacial rather than interglacial periods—brings into question the regional climatic significance of these taxa in the marine record. It is inferred by Zheng and Lei (1999) that glacial periods generally remained wet, although the last glacial period was an exception, with abnormally high values for Poaceae and the only significant values for *Artemisia* interpreted as indicating much drier conditions than present. Temperatures are estimated, from an inferred lowering of montane forest by at least 600 m, to have been some 4°C lower than today during earlier glacial periods, and even lower during the last glacial period. However, there is little variation in lowland forest elements through the record.

4.4.2 The Coral Sea region

Marine records from the Coral Sea adjacent to the humid tropics region of northeastern Australia provide a coarse resolution coverage of much of the last 10 Myr (Kershaw *et al.*, 1993, 2005; Martin and McMinn, 1993) (Figures 4.1 and 4.7). Throughout almost all of the period, the dry land pollen assemblages are dominated by the rainforest taxa Araucariaceae (predominantly *Araucaria*) and *Podocarpus* that, in this region, may have been abundantly represented in lowland as well as higher altitude communities, and the predominantly sclerophyll taxon Casuarinaceae. Late Miocene to Early Pliocene assemblages also contain notable percentages of other montane rainforest taxa—especially *Dacrydium guillauminii* type, *Dacrycarpus*, *Phyllocladus*, and *Nothofagus*—while rainforest angiosperms (including lowland taxa, herbs, and mangroves) are poorly represented. The climate was wet and probably substantially cooler than today. There is a gap in the record from the Early Pliocene to the very early Quaternary, but dominance of a Late Pliocene terrestrial sequence on the Atherton Tableland by *Podocarpus*, *Nothofagus*, and Casuarinaceae, with the full complement of southern conifers, suggests a continuation of wet and cool conditions until at least close to Pleistocene times (Kershaw and Sluiter 1982). The reduced representation of *Araucaria* at this site can be explained by the per-humid conditions as araucarian forest is generally confined to drier rainforest margins. Conversely, *Nothofagus* would have thrived under the high rainfall as well as the higher altitude of the Tableland.

At the time of recommencement of pollen preservation in the marine record about 1.6 Myr, values for Casuarinaceae, Araucariaceae, and *Podocarpus* are maintained, but other southern conifers have much reduced percentages, with *Phyllocladus* having

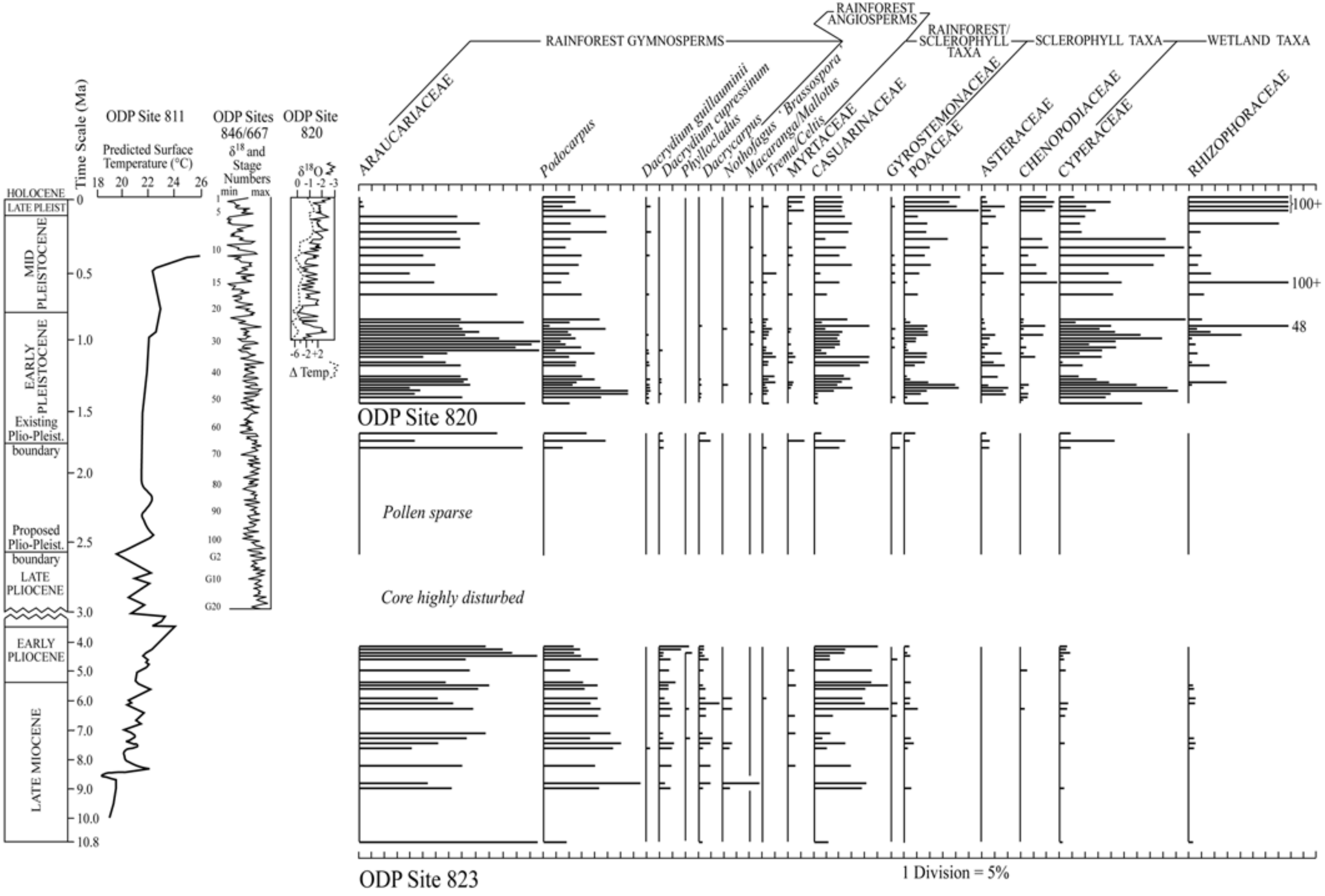

Figure 4.7. Representation of major and indicator taxa in pollen records from ODP Site 823 (Martin and McMinn, 1993) and ODP Site 820 (Kershaw *et al.*, 1993) in relation to the Coral Sea marine isotope record from ODP Site 820 (Peerdeman, 1993) and inferred sea surface temperature records from ODP Sites 820 and 811, and the combined "global" isotope record of Sites 846 and 667 (Shackleton *et al.*, 1995). All terrestrial pollen, excluding mangroves and pteridophyte spores, make up the pollen sum on which all percentages are based.

disappeared from the record. *Nothofagus* also was probably regionally extinct with occasional grains most likely derived by long-distance transport from New Guinea There are marked increases from 1.4 Myr in Poaceae, Asteraceae, Chenopodiaceae, rainforest angiosperms, and mangroves, but—as the record changes at this point from a deep-sea (ODP Site 823) to a continental slope (ODP Site 820) core—these changes may reflect differential pollen transport as much as source vegetation. However, differences between Late Tertiary and Early Pleistocene assemblages do indicate that rainfall had declined and temperatures had possibly increased. The trend in the marine isotope record from the Coral Sea towards less negative values, interpreted as an increase in sea surface temperatures, provides support for a regional temperature increase (Isern *et al.*, 1996).

Most of the Quaternary period is characterized by very variable representation of taxa. Although sample resolution is too coarse to address the cause of this variation, a detailed record from at least 1 Myr to about 950 kyr (Kershaw *et al.*, 2005) demonstrates a relationship with oscillations in the isotope record of Peerdeman (1993) that extends back to within this phase. Rainforest conifers, Casuarinaceae, and Poaceae achieve greater relative importance than rainforest angiosperms during glacial periods, indicating they were both cooler and drier than interglacials. However, the sequence remains fairly stationary until late in the record, with the only substantial change being the loss, probably within the Mid-Pleistocene Transition, of *Dacrycarpus*.

The most dramatic modification of the vegetation cover of the humid tropics of Australia within the Quaternary and, in fact, during the whole of the last 10 million years, is recorded within the last 200 kyr. This modification follows a sharp decline between 350 kyr and 250 kyr in δ^{18}O values of planktonic foraminifera within ODP Site 820 (Peerdeman 1993) that correlated with a major phase of development of the present Great Barrier Reef system (Davies, 1992). It has been proposed that the isotopic change was a result of increased sea surface temperatures within the Coral Sea (Peerdeman *et al.*, 1993; Isern *et al.*, 1996), but this hypothesis is not supported by alkenone paleothermometry that suggests temperatures have not varied by more than 1.5°C over the last 800,000 years and that diagenesis within foraminifera is a more likely explanation for the isotope trend. A detailed record through the last 250 kyr from ODP Site 820 (Moss, 1999; Kershaw *et al.*, 2002) illustrates the complex nature of the vegetation changes (Figure 4.8). Dates are derived from the accompanying isotope record (Peerdeman, 1993), but—due to potential hiatuses and changes in sediment accumulation rates—are not very precise. Higher values for rainforest angiosperms in this detailed record are probably due to a reduction in sieve size during preparation, allowing the collection of small grains such as *Elaeocarpus* and Cunoniaceae. Glacial–interglacial cyclicity is most evident in the rainforest angiosperm and mangrove components that are highest during interglacial periods and during interglacial transgressions, respectively, but is over-ridden by stepwise changes in other major components. There is a substantial and sustained increase in Poaceae around 180 kyr with apparent compensatory decreases in pteridophyes and Arecaceae. Southern conifers decrease through the record with the last major representation of *Podocarpus* and *Dacrydium* about 190 kyr: the latter disappearing from the record around 25 kyr, and sustained decreases in Araucariaceae about 140 kyr and

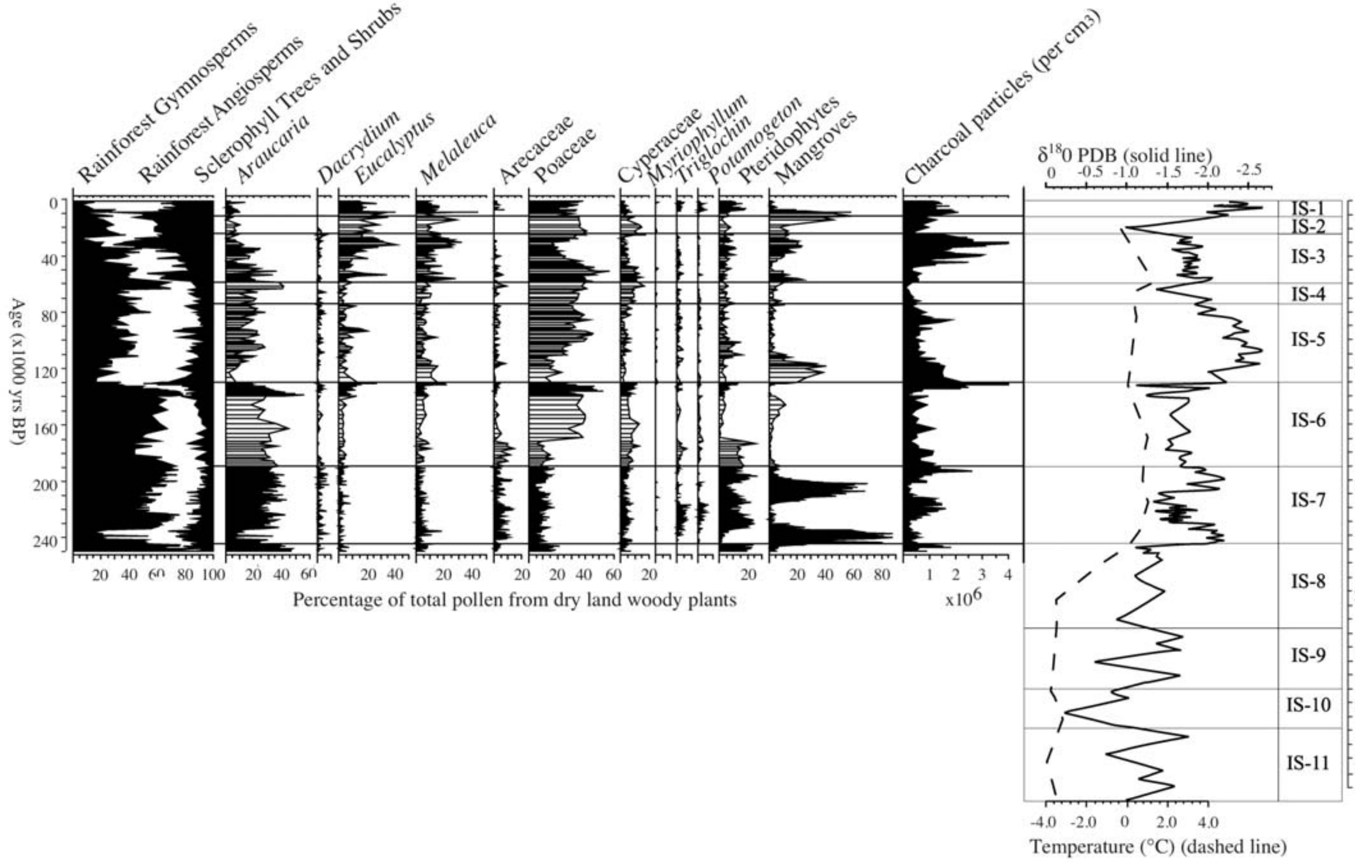

Figure 4.8. Selective features of the detailed Late Quaternary record from ODP Site 820 (Moss, 1999) in relation to the marine isotope record of Peerdeman *et al.* (1993). All taxon abundances are expressed as percentages of the dry land arboreal pollen sum (excluding aquatics, mangroves, and pteridophytes).

30 kyr. By contrast, *Eucalyptus* increases from very low values around 130 kyr and increases again around 40–30 kyr, with rises corresponding to highest charcoal peaks in this record. There is little sustained change in representation of rainforest angiosperms, although the trend towards higher values for Cunoniaceae—resulting in a greater contribution of sub-montane pollen—certainly does not support a general temperature increase. Many of these changes are identified within the later part of the record by those in the adjacent terrestrial record of Lynch's Crater: notably, the initiation of burning around the site, dated to about 45 kyr (Turney *et al.*, 2001), with a sustained increase in *Eucalyptus* and decline in *Araucaria* a few thousand years later, and a similar age for the disappearance of *Dacrydium*. However, there is no evidence for sustained changes before this time, back to the initiation of the record about 220 kyr (Kershaw *et al.*, 2002).

4.5 THE LATER PLEISTOCENE

A more spatially representative picture of changes in the distribution and composition of rainforest can be constructed for the later part of the Pleistocene from a greater number of sites that, in addition to those from ODP Sites 1144 and 820, provide continuous or near-continuous palynological records through at least the last glacial cycle (Figure 4.1). The record from core SHI-9014 in the Banda Sea (van der Kaars *et al.*, 2000) provides the most substantial evidence of vegetation change in the rainforest core of Southeast Asia and a framework for examination of variation within the broader area (Figure 4.9). The regional significance of the Banda Sea record is demonstrated by its remarkable similarity to a recent record from core MD98-2175 in the adjacent Aru Sea (van der Kaars, new data). Rainforest is a prominent component of the pollen spectra throughout, although the substantial sclerophyll component—largely *Eucalyptus*, that would have been derived mainly from the Australian mainland—demonstrates a very broad pollen catchment area. Highest rainforest and pteridophyte values occur during interglacials, indicating that they were much wetter than glacial periods. However, expansion of the Sahul continental shelf during times of low sea level, much of which appears to have been covered largely by grassland (Chivas *et al.*, 2001), would have resulted in excessive Poaceae representation and probable exaggeration of moisture variation through the recorded period. Wet conditions and the maintenance of near-continuous rainforest are certainly evident in some areas—such as highland New Guinea (Walker and Flenley, 1979) and much of the island of Borneo (Anshari *et al.*, 2004; Morley *et al.*, 2004) during the last glacial period, including the Last Glacial Maximum. However, grassland may have disrupted forest growth in more peripheral rainforest (see Section 4.6). The Banda Sea record displays higher values for upper montane taxa during interglacial than glacial periods, and this is surprising considering the abundant evidence from sites in highland parts of the region for much expanded montane vegetation with substantial temperature lowering (see Section 4.6 for discussion of this). This Banda Sea pattern may be a result of an overall reduction in lowland rainforest that is demonstrated to have covered at least parts of the Sunda continental shelf within core rainforest areas during the last glacial period (Morley *et*

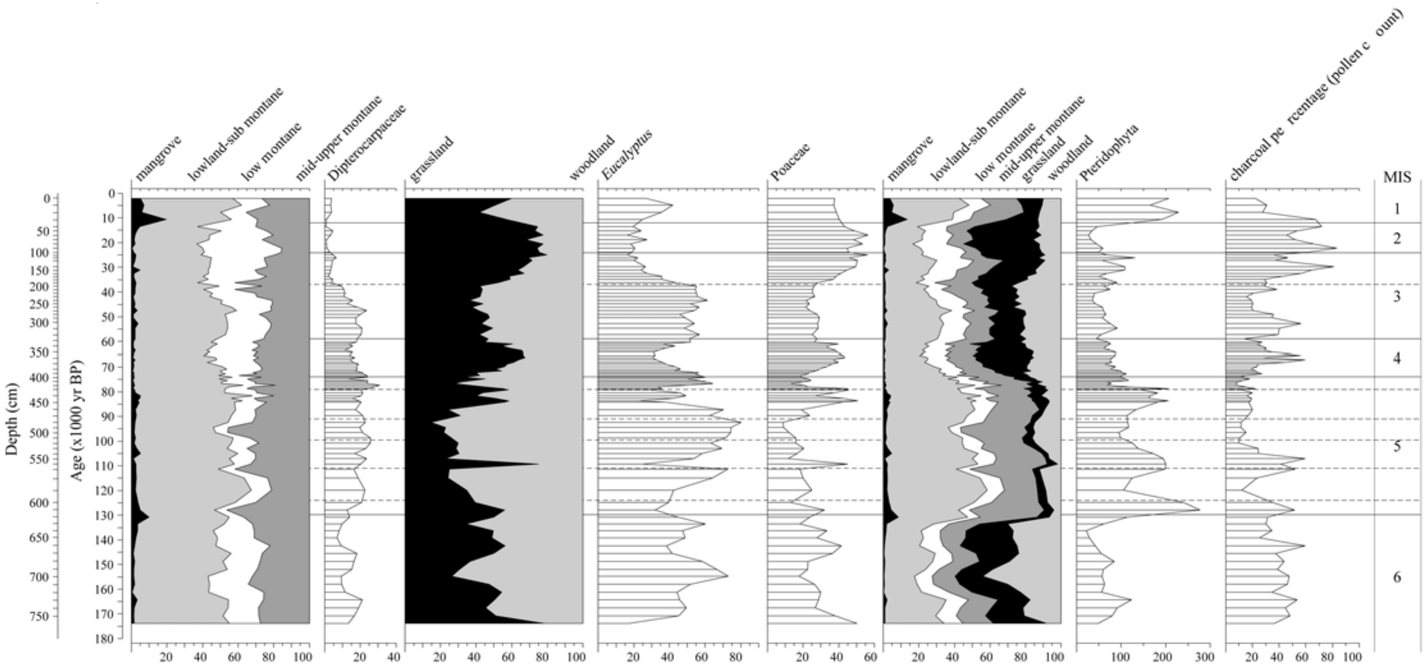

Figure 4.9. Selected features of the pollen and charcoal record from Banda Sea core SHI-9014 in relation to the marine isotope record (adapted from van der Kaars *et al*., 2000). All taxa are expressed as percentages of the rainforest pollen sum.

al., 2004). It may also be the case that the present day terrestrial area of lowland rainforest was little reduced during glacial periods if there was a smaller degree of temperature lowering at low altitudes. One feature of the Banda Sea record that is shared with those from the Aru Sea and Sangkarang-16, offshore Sulawesi, is a dramatic and sustained reduction in pollen of the dominant lowland rainforest family Dipterocarpaceae about 37 kyr. It is possible that the present pattern of representation of the family—that is lower in abundance and diversity in the eastern than western part of the region—is as much the result of this Late Pleistocene event as it is of the historical barrier of Wallace's Line to migration of the Indo-Malaysian flora westwards as generally assumed (Whiffin, 2002). As this Dipterocarpaceae is associated with an increase in charcoal, burning is regarded as the primary cause, and the impact of early people—rather than climate—has been postulated as its major cause (van der Kaars *et al.*, 2000). Similar sustained increases in charcoal recorded in long marine cores from the Sulu Sea (Beaufort *et al.* 2003) and to the north of New Guinea (Thevenon *et al.*, 2004)—but from a different time, about 52 kyr—have been considered as providing support for the human burning hypothesis.

A rare insight into the history of rainforest on the dry margin of rainforest distribution is provided by marine core MD98-2167 in the North Australian Basin, off the coast of the Kimberley Ranges of northwestern Australia (Figure 4.10). Here,

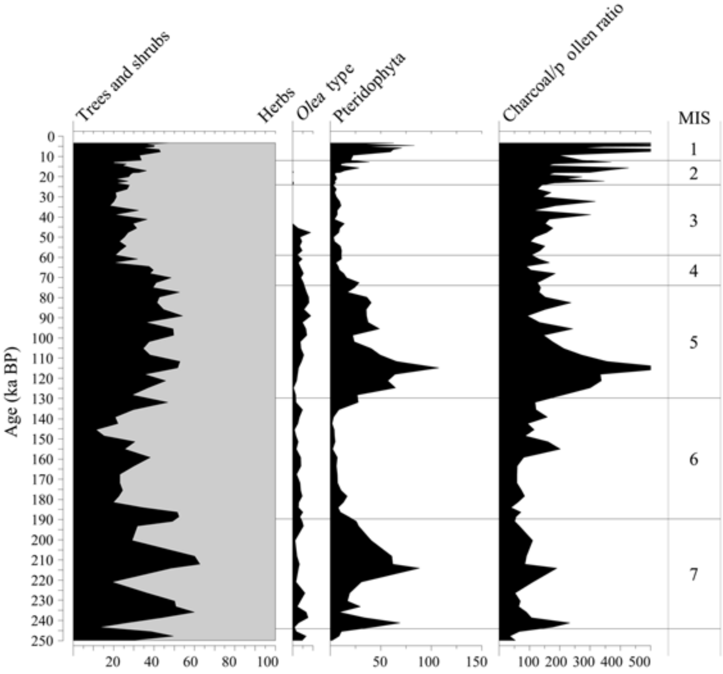

Figure 4.10. Selected features of the pollen and charcoal record from the North Australian Basin core MD98-2167 (Kershaw *et al.*, in press; van der Kaars, unpublished data) in relation to the marine isotope record of Brad Opdyke (unpublished data). All taxa are expressed as percentages of the total dryland pollen sum.

deciduous vine thickets exist in small pockets surrounded by eucalypt-dominated savanna woodland. The major representative of these vine thickets—that have generally poor pollen dispersal—is considered to be *Olea* type. It has low but relatively consistent representation through the record—showing little response to inferred changes in rainfall as indicated by broad glacial–interglacial changes in relative abundance of tree and shrub pollen, that derive largely from the Kimberley region—and particularly the pteridophyte spores that must have been derived from the core rainforest area of Indonesia. Burning appears to have increased around 130 kyr, without any notable change to the vegetation structure, apart from some evidence for increased variability in tree and shrub to herb representation. However, major changes occurred around 46 kyr that included the total disappearance of *Olea* type from the record. This decline in *Olea* may have been associated with a general further increase in burning that has continued to the present.

4.6 THE LAST GLACIAL MAXIMUM (LGM) TO HOLOCENE

A much greater spread of site records as well as more detailed analysis of sites during this period is available than for previous ones (Figure 4.1), allowing more refined investigation of temporal and spatial patterns both within rainforest and between rainforest and more open vegetation communities. Of particular interest are the extent of rainforest and altitudinal shifts in rainforest communities during the LGM that inform debates on contemporary precipitation and temperature levels.

4.6.1 Last Glacial Maximum

The idea that lowland rainforests might have been replaced by grassy savannas at the LGM is clearly not substantiated from the evidence from longer records, but there is some evidence of savanna expansion. The actual degree and areal expression of this expansion is hotly debated. In some more marginal rainforest areas, savanna vegetation did replace rainforest in part—as around Rawa Danau (van der Kaars *et al.*, 2001) and the Bandung Basin (van der Kaars and Dam, 1995)—or totally—as on the Atherton Tableland in northeastern Australia (Kershaw, 1986)—but increased representation of grasses in coastal sites may have been reflecting more open vegetation on exposed continental shelves or an increased aquatic component. Greatest debate has been over the potential existence of a north–south dry corridor extending through Malaysia and between Sumatra and Borneo during the LGM. At one extreme is the view of Morley (2000, 2002) who considered that rainforest massifs, or refugia, were essentially restricted to southwestern Borneo and the adjacent Sunda Shelf, the western part of Sumatra, and very western tip of Java (see Chapter 1). Major migration of rainforest is implied between glacials and interglacials unless high diversity was conserved in river gallery forests, a situation proposed for northeastern Australia during the last glacial period (Hopkins *et al.*, 1993). Kershaw *et al.* (2001), on the other hand, see little evidence for such a dry corridor, at least during the last glacial period. Evidence is sparse and their interpretation is based largely on the almost complete dominance of rainforest pollen in submerged peat cores from the Sunda Shelf off southeastern Sumatra (van der Kaars, unpublished data). Although undated, the peat almost certainly derives from the last glacial period rather than any earlier period as it is unlikely to have survived subsequent low sea level stands.

There is general consensus, however, that—in accordance with the reconstruction of Morley (2000)—much of Borneo retained rainforest and that this forest extended over the continental shelf within the South China Sea region. Confirmation of the maintenance of a rainforest cover within inland West Kalimantan is provided by Anshari *et al.* (2001, 2004), although drier conditions during the later part of the last glacial period are evident, while a marine pollen record from core 17964 in the southern part of the South China Sea (Sun *et al.*, 1999) further substantiates the dominance of a rainforest cover.

In comparison with lowland sites, those from the highlands show the clear maintenance of rainforest through the LGM. Here attention has focused on altitudinal changes in representation of rainforest components. There is good pollen evidence from several sites showing movement of montane tree taxa to lower altitudes. An excellent example of this migration is seen in the pollen diagram from the swamp at the edge of Lake di-Atas in Sumatra (Newsome and Flenley, 1988). The site is at 1,535 m a.s.l., and—where the forest around the lake survives—it is dominated by a variety of tropical oak taxa: *Lithocarpus*, *Castanopsis*, and *Quercus*. It is believed that formerly the tree *Altingia excelsa* (Hamamelidaceae) was abundant also (van Steenis, 1972), but it has been selectively logged. Above 1,800 m the forest changes sharply and becomes dominated by gymnosperms: *Dacrycarpus imbricatus*, *Podocarpus neriifolius* and (in swamps) *Dacrydium* cf. *elatum*. Even *Pinus merkusii* is present, its only natural occurrence in the southern hemisphere. There are also angiosperm trees, the most conspicuous being *Symingtonia populnea*. The diagram (Figure 4.11) shows that in a phase dated to between c. 18 kyr and c. 12 kyr BP (c. 22–14 kcal. yr BP) all those gymnosperms are prominent in the record, only to disappear in the Holocene and be replaced by the distinctive pollen of *Altingia* (previously rare) and peaks of *Quercus* and *Lithocarpus*/*Castanopsis*. This replacement strongly suggests a climate cooler at the LGM, perhaps by 2°C or more. Interestingly, there is an inversion of radiocarbon dates around ^{14}C kyr BP, which could be explained by lower water tables, permitting erosion of swamp sediments and their redeposition within the core. This depositional event would correlate with the drier lowland Pleistocene climates already mentioned.

Confirmation of these results comes from a site in Java at c. 1,300 m—Situ Bayongbong (Stuijts, 1984)—that is close to the Bandung basin site. Lower altitude sites in Sumatra (Maloney, 1981, 1985, 1998; Morley, 1982; Maloney and McCormac, 1995) also are supportive. These data bring the records of montane gymnosperms down to 1,100 m at c. 22 kcal. yr BP and do not conflict with the Bandung occurrence of *Dacrycarpus* pollen at 650 m, and at Rawa Danau at only c. 100 m (van der Kaars *et al.*, 2001). Collectively, therefore, these results support the Bandung estimate (van der Kaars, 1998) of a climate cooler at the LGM by as much as 4°C or 5°C.

The incursion of montane elements into lowland areas could have been even more marked. The site at Kau Bay in Halmahera (Barmawidjaya *et al.*, 1989) is at present-day sea level. This flooded volcanic crater was a freshwater lake when sea level was

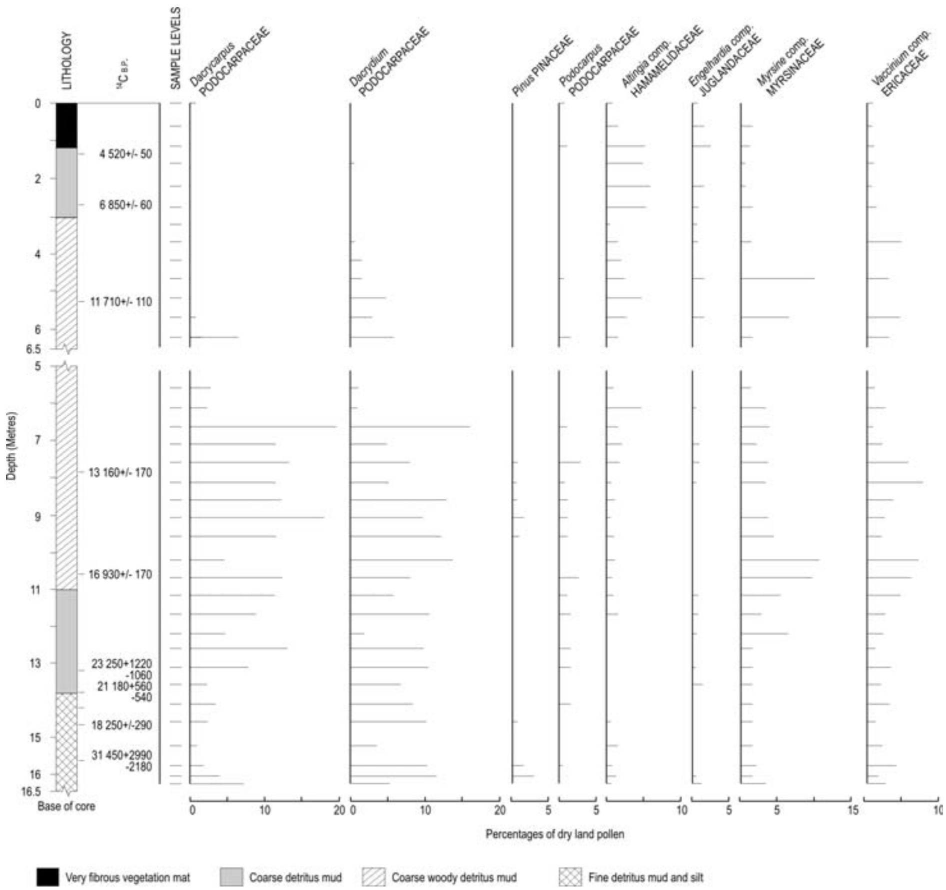

Figure 4.11. Pollen diagram from Danau di Atas Swamp, West Sumatra, altitude 1,535 m. Values are given as percentages of total dry land pollen. Only selected taxa are shown. After Newsome and Flenley (1988) and Stuijts *et al.* (1988).

lower by >100 m at the LGM. Palynology of this site showed occurrences of *Castanopsis*/*Lithocarpus* and *Quercus* at the LGM. While it is not suggested that these taxa necessarily grew at present sea level, they apparently grew close enough for small amounts of their pollen to enter the record. This record would be consistent with a temperature lowering of c. 6°C at the LGM, even in the lowlands. Similar results have been obtained from lowland sites in West Kalimantan (Anshari *et al.*, 2001, 2004).

There is also evidence from the highest mountains of Indonesia for Pleistocene cooling of as much as 6°C. Leaving aside the evidence from New Guinea, we have evidence of Pleistocene glaciation on Mt. Kinabalu in northern Borneo (Koopmans and Stauffer, 1968) and of deglaciation around 8,000 BP (c. 10 kcal . yr BP) at 4,000 m a.s.l. (Flenley and Morley, 1978). Similar evidence (for solifluction at least) is claimed for the slightly lower peak of Gunong Leuser (3,381 m) in northern Sumatra (Beek, 1982).

In New Guinea the best evidence of environmental change comes from upland regions. The site at Sirunki (Walker and Flenley, 1979) appears to cover the last 33 kyr (c. 40 kcal. yr BP), at an altitude of 2,500 m a.s.l. The site currently lies in *Nothofagus* forest (much disturbed), and is some 1,300 m below the altitudinal forest limit at c. 3,800 m a.s.l. Nevertheless the pollen record clearly shows the presence of tropic-alpine herbs (*Astelia*, *Gentiana*, *Drapetes*, etc.) in the Late Pleistocene, when forest pollen values decline to a level consistent with unforested conditions. Similar results were obtained from Lake Inim at 2,550 m by Flenley (1972) (Figure 4.12).

There is, of course, geomorphological evidence of lowered snow lines (U-shaped valleys, moraines, etc.) in the New Guinea mountains. On Mt. Wilhelm, a lowering in the Late Pleistocene of c. 1,000 m is indicated (Löffler, 1972), and there are similar findings from Irian Jaya (Hope and Peterson, 1975). One thousand metres translates into perhaps 6°C cooling, using a modern lapse rate.

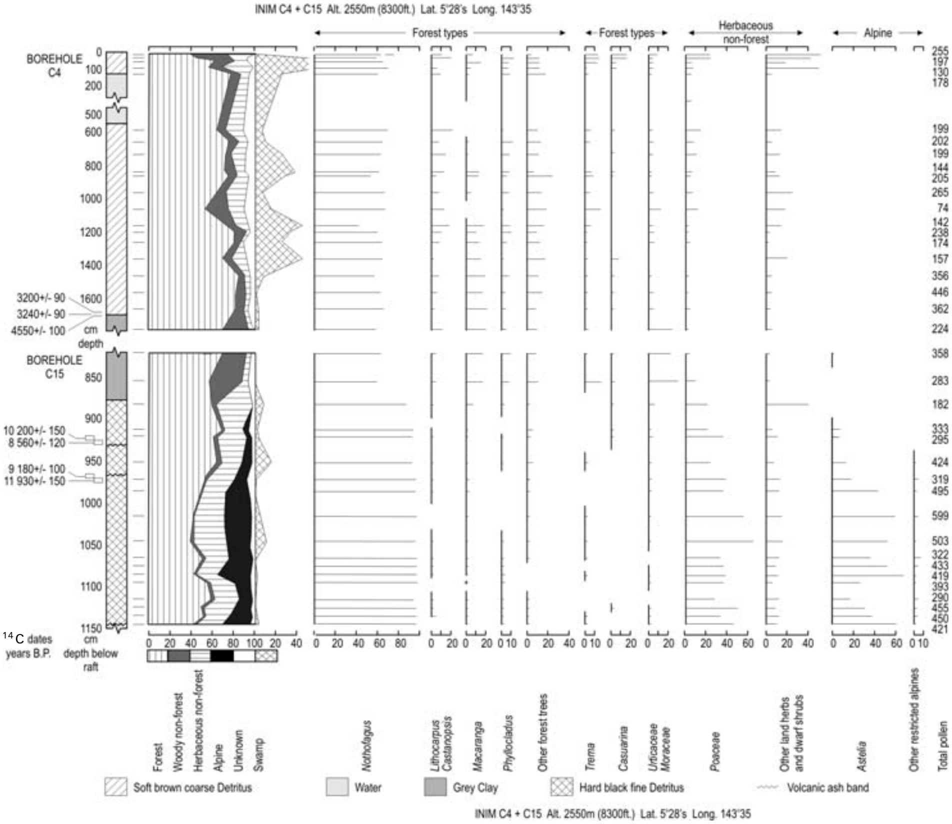

Figure 4.12. Pollen diagram from Lake Inim, boreholes C4 and C15, plotted on the same scales. The results are expressed as percentages of pollen of forest types, except in the summary diagram where the total of dry land pollen and spores forms the pollen sum. Only selected taxa shown. After Flenley (1972).

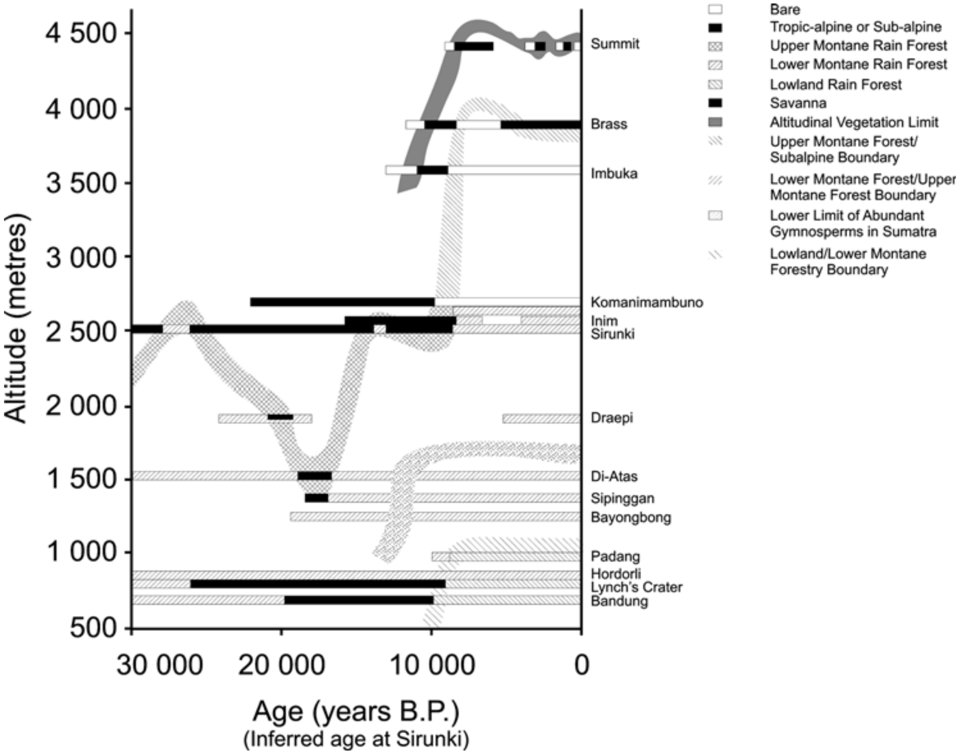

Figure 4.13. Selected vegetation records derived from pollen diagrams from tropical Southeast Asia and the West Pacific. Only the last 30,000 years are shown. Human impact is omitted. References to individual sites are as follows: Summit, Brass, Imbuka, Komanimambuno (Hope, 1976), Inim (Flenley, 1972; Walker and Flenley, 1979), Sirunki (Walker and Flenley, 1979), Draepi (Powell *et al.*, 1975), Di-Atas (Newsome and Flenley, 1988), Sipinggan (Maloney, 1981), Bayongbong (Stuijts, 1984; Stuijts *et al.*, 1988). For other sites see Flenley (1998). After Flenley (1998).

At the LGM, climates cooler than now by as much as 7–11°C can be suggested from the pollen results, but only c. 6°C from the geomorphology. How can this be? Possibly, snow lines were kept artificially high by the reduced precipitation that probably occurred at the LGM. This suggestion has been advanced by Walker and Flenley (1979). But, the precipitation in the mountains cannot have been too reduced, or rainforests would have disappeared there. Late Quaternary vegetational changes are summarized in Figure 4.13.

This whole question has been reviewed by Pickett *et al.* (2004) in a reconstruction of Quaternary biomes for the Southeast Asian region, Australia, and the Pacific. They conclude that the evidence from the Southeast Asian tropics indicates an LGM cooling of 1–2°C at sea level and 6–9°C at high elevation sites. This discrepancy was first noted by Walker and Flenley (1979), who attributed it to a steeper lapse rate, which was itself related to the generally drier conditions at the LGM, leading to a lapse rate closer to the dry adiabatic lapse rate. Such a steeper lapse rate was however criticized as impossible in an environment where the pollen evidence clearly showed the persistence of rainforests (Webster and Streten, 1972; Kutzbach and Guetter, 1986).

The idea has however been revived by Farrera *et al.* (1999) who give a range of plausible mechanisms by which a steeper lapse rate can occur on tropical mountains. One among these was the observation that the moist adiabatic lapse rate steepens anyway as temperature is lowered (Hartmann, 1994). Another relevant point is the possible impact of reduced concentrations of carbon dioxide at the LGM (Street-Perrott, 1994), which would favour C_4 plants (grasses) at the expense of trees.

A steeper lapse rate alone is however unable to explain all aspects of observed vegetation changes. Hope (1976) demonstrated—regarding Mt. Wilhelm—the curious fact that the Upper Montane Rain Forest (UMRF) (cloud forest) did not simply migrate downhill at the LGM: it virtually disappeared. This is not a Late Pleistocene anomaly, for Upper Montane taxa were greatly reduced in each glacial period in the Banda Sea record (see Section 4.5). To understand this phenomenon we must consider the physiognomy and environment of the UMRF at the present time (Flenley, 1992, 1993). The trees are stunted, with short internodes and small thick leaves which possess a hypodermis (an extra layer of cells below the epidermis). Often extra pigments are present as well as chlorophyll: usually flavonoids and/or anthocyanins. These attributes are typical of plants experiencing stress of various kinds, including high ultraviolet-B and temperature extremes. The soils are unusual in the thickness of their litter layer. The temperature environment shows extreme variations on a diurnal basis: from very cold nights and early mornings, to sunny mornings and misty afternoons with 100% humidity. The morning insolation is high in ultraviolet-B because of the altitude. It is known that high UV-B can produce experimentally in crop plants exactly the same physiognomic peculiarities as the Upper Montane Rain Forest (Teramura, 1983), and can also inhibit insect activity, leading to thick litter layers in soils (Day, 2001). It therefore seems possible that UV-B is involved in the ecology of these forests. It may well be that the extreme diurnal variation of the temperature regime is also involved.

How does all this help to explain the decline of the UMRF in cold phases of the Pleistocene? Presumably, when cooler temperatures forced taxa downhill, they found themselves in an environment where the diurnal extremes of temperature and UV-B no longer existed to the same extent. The tropical lowlands are in fact usually lacking in such extremes. Assuming the UMRF taxa are genetically adapted to their present environment, the disappearance or great restriction of that environment at the LGM would have led to their reduction in the pollen record (Flenley, 1996, 1998). This argument will be elaborated in Chapter 8.

4.6.2 The Pleistocene–Holocene transition

Marine records generally show abrupt pollen shifts from glacial to interglacial conditions, suggesting strong Milankovitch forcing of climate and rapid response of the vegetation. However, altered boundary conditions, including those related to coastal landscapes and oceanic and atmospheric circulation, may have played a part in producing this degree of synchroneity. A major exception related to the Coral Sea record of ODP 820 where an increase in rainforest lags the marine isotope change from MIS 2 to 1 by several thousand years. As this lag is also evident in the Lynch's Crater record (Kershaw, 1986), it cannot easily be attributed to global climate forcing. Possible explanations are: the time taken for rainforest patches to expand from glacial "refugia" (unlikely considering the regional extent of rainforest during the last glacial period); the influence of southern hemisphere insolation forcing including ENSO on the record; and the continuing impact of Aboriginal burning; all of which slowed the rainforest advance. More detailed analysis of the earlier part of the ODP 820 record may help resolve this question.

Many terrestrial records are too coarse or insufficiently well-dated to detail local patterns of change during the last termination. However, at an altitude of 3,630 m in Irian Jaya, there is supporting evidence for a rapid replacement of grasslands and scattered shrubs by rainforest at the Pleistocene–Holocene boundary. Similar changes are evident at Lake Inim (Flenley, 1972) and in the elegant suite of sites on Mt. Wilhelm, the highest mountain in Papua New Guinea (Hope, 1976). With four sites at elevations from 2,750 m to 3,910 m, Hope was able to trace the deglaciation of the mountain and the rapid climb of the altitudinal forest limit to about 4,000 m in the early Holocene.

Walker and Flenley (1979) found a hint of a Late Pleistocene oscillation at Sirunki, though its age of c. 17 kcal.yr BP does not correlate well with the Younger Dryas and is more consistent with the Antarctic Reversal. Support for such an oscillation has recently been demonstrated from a detailed analysis of the last termination at Rawa Danau in Java (Turney *et al.*, 2006). Towards the end of the LGM (Turney *et al.*, in press), high values for grass pollen—combined with the presence of the montane trees *Dacrycarpus*, *Podocarpus*, and *Quercus*—indicate much drier and cooler conditions than today. Initial increases in temperature and rainfall are recorded as early as 17 kcal.yr BP with increased representation of lowland rainforest taxa and reduction in Poaceae. There is then a reversal of this trend between 15.4 kcal.yr BP and 14.6 kcal.yr BP, prior to both the Antarctic Reversal and Younger Dryas, suggesting a regional tropical rather than hemispheric control over climate variation. Although rainforest became dominant at 14.6 kcal.yr BP, increased catchment erosion suggests rainfall further increased around 12.9 kcal.yr BP and that the summer monsoon may not have become fully established until the early Holocene.

4.6.3 The Holocene

Rainforest achieved its maximum areal extent in the Early–Middle Holocene under high levels of precipitation and temperature before it opened up again mainly within the last 5,000 years. Reasons for this rainforest reduction include climate factors, although these varied regionally. Hope (1976) attributes a reduction in the altitudinal treeline of about 200 m to a reduction in temperature in New Guinea, while seasonality or increased ENSO influence is considered to have been the major influence on both a change in the composition of rainforest and slight sclerophyll woodland expansion in northeast Queensland (Kershaw and Nix, 1989; McGlone *et al.*, 1992; Haberle, 2005). However, the major impact on Holocene rainforest has been that of people.

Although people have been in the region for around 1.8 million years (Swisher *et al.*, 1994; Huffman, 2001) and have had the ability to manage vegetation through the use of fire within the last 100 kyr, the ability of people to physically clear rainforest for agriculture is essentially a Holocene phenomenon within the region. There are indications of agriculture (for rice-growing) as early as 16 kcal.yr BP in the Yangtze Valley, China (Yasuda, 2002)—an area recognized as one of the cradles of crop domestication (Vavilov, 1951; Diamond, 1998)—and its spread into Southeast Asia, including those parts of the Sunda Platform which were then joined to the Asian Mainland. Several upland sites in Sumatra suggest that swiddening (slash-and-burn) was occurring for cultivation of dry (non-irrigated) rice or root crops as early as c. 10.3 kcal.yr BP at Danau-di-Atas (Newsome and Flenley, 1988), c. 10 kcal.yr BP at Pea Bullok (Maloney and McCormac, 1995), and c. 9 kcal.yr BP at Rawang Sikijang (Flenley and Butler, 2001). The general pattern of evidence for the region was reviewed by Maloney (1998) and Flenley (2000).

A separate center for the origin of agriculture is found in New Guinea, based on rootcrops—such as *Colocasia* (taro)—and palynological evidence of forest destruction presumably for agriculture dates back to c. 9 kcal.yr BP in the Baliem Valley (Haberle *et al.*, 1991), to c. 6 kcal.yr BP or earlier at Draepi Swamp (Powell *et al.*, 1975), and to 5 kcal.yr BP at Sirunki Swamp (Walker and Flenley, 1979). Early human activity in the New Guinea Highlands was confirmed by archeological finds at Kuk Swamp (Golson and Hughes, 1976; Golson, 1977; Denham *et al.*, 2003). These included evidence of swamp drainage, presumably for the growing of taro, back to at least 6.8 kcal.yr BP and possibly c. 10 kcal.yr BP. The destruction of swamp forest on Lynch's Crater about 5 kcal.yr BP suggests that some form of cultivation may have spread into the rainforest areas of northeastern Australia at this time.

The progressive impact of these activities has led to the creation of permanent grasslands in many areas. These include the *cogonales* of the Philippines, the *kunai* of New Guinea, and smaller areas in Sumatra and elsewhere. In general, these areas have been maintained by frequent burning, and they tend to occur in regions where there is a more lengthy dry season (Thomas *et al.*, 1956). Recently, agriculture and logging has of course still further diminished the area of surviving forest, but consideration of that is beyond the scope of this chapter.

4.7 VEGETATION RESPONSES TO CYCLICAL FORCING

Spectral analysis is a powerful tool for examination of cyclical variation within components of well-dated, largely marine, records and has been applied to a number of sequences within the far eastern rainforest region in order to assess responses of various proxies to potential forcing mechanisms on orbital timescales.

Analysis of ODP Site 1144 in the South China Sea was restricted to pine and herb pollen, essentially winter monsoon indicators, and demonstrated clear Milankovitch forcing with prominent 100 kyr (eccentricity), 40 kyr (obliquity), and 20 kyr (precession) periodicities, in phase with northern hemisphere insolation and ice volume and indicating a clear link with monsoon activity (Sun *et al.*, 2003). It is interesting that the herbs demonstrate a closer correspondence with the ice volume signature than pine, reinforcing the suggested higher latitude source of its pollen. Pine displays a higher precessional than obliquity peak, indicating some tropical influence. It also shows a strong semi-precessional frequency that may be the result of an additional southern hemisphere tropical precessional signal resulting from changing mean position of the Intertropical Convergence Zone through time. Unfortunately, as spectral analysis was performed on the whole million-year record, there is no way of determining changes in forcing through time—that may be expected with a change in the global signal—from dominant obliquity to eccentricity forcing around the Brunhes–Matuyama boundary.

A greater range of proxies has been examined from the southern hemisphere sites of Banda Sea, Lombok Ridge, and ODP 820 (Kershaw *et al.*, 2003) and the North Australian Basin (van der Kaars, new data). In general terms, mangroves show similar frequencies to those from associated oxygen isotope records, and indicate strong northern hemisphere forcing. With mangroves, this pattern is not surprising as they are constrained by sea level changes that relate directly to ice volume. Their closer relationship with variation in sea level rather than that of climate has been explained by Grindrod *et al.* (1999, 2002). It is the broad exposure of the continental shelf during marine transgressions that facilitates mangrove colonization and peak mangrove pollen representation.

The major indicators of core rainforest—pteridophytes and rainforest angiosperms—surprisingly exhibit rather different spectral signatures. Pteridophytes exhibit strong glacial–interglacial cyclicity with a prominent obliquity signal that is not evident in the rainforest angiosperms that display a dominant precessional signal, except in the Banda Sea record. The most parsimonious explanation is that the core rainforest area is greatly influenced by the Asian monsoon and this influence extends to other marine sites in the pteridophytes due to the wide dispersal of their spores. The implication that more marginal areas are displaying a more localized tropical precessional influence is well-demonstrated in the eucalypt component of the North Australian Basin, whose variation can be clearly correlated with that of southern hemisphere precession. Although the area expresses a marked monsoon climate, the source of monsoon rainfall is most probably the southern Indian Ocean that is largely divorced from the Asian system.

Rainforest angiosperms also display significant variation in the 30-kyr frequency band, and this frequency is even more clearly expressed in rainforest gymnosperms and some charcoal records. It has been proposed by Kershaw *et al.* (2003) that this non-Milankovitch cycle is related to ENSO, due to the correspondence of peaks in burning and associated declines in fire-sensitive araucarian forests in the ODP record with peaks in ENSO frequency derived from the modelling of Clement *et al.* (1999). From similar spectral signatures in the records of charcoal from cores MD97-2141 and MD97-2140 in similar West Pacific settings, Beaufort *et al.* (2003) and Thevenon *et al.* (2004) propose that the 30-kyr frequency can be attributed to the competing influences of long-term ENSO-like forcing and the glacial–interglacial cycle on the East Asian Summer Monsoon.

4.8 GENERAL DISCUSSION AND CONCLUSIONS

Perhaps the major feature of the Quaternary history of far eastern rainforest is that there has been little overall change in gross distribution over most of the area and through most of the period. Rainforest has shown tremendous resilience in the face of increasingly variable climatic conditions that have seen its partial replacement by more open vegetation types during drier and cooler glacial phases. The major spatial exception to this pattern is in tropical Australia, where the extensive occurrence of small patches of drier rainforest demonstrates survival from a much broader past distribution. This must pay testament to the aggressive nature of fire-promoting eucalypts, as it appears that grasslands alone have had much less of a long-term impact on similar vegetation in the Southeast Asian region, although poor soils and extreme climatic variability over much of tropical Australia may have contributed to this pattern. This patchy distribution is evident through the last 500 kyr in northern Australia, and it can only be surmised that this is a product of the Quaternary rather than a geologically earlier period.

In northeastern Australia, however, the impact of the Quaternary is clear with widespread reduction in drier araucarian forest within the late Quaternary. There has been speculation into the cause of this decline, elaborated by Kershaw *et al.* (2006). One explanation is human impact. However, without any evidence of the presence of people on the continent before about 50–60 kyr ago, this line of speculation is not particularly constructive, although there seems little doubt that, with the arrival of people, the trend towards more open vegetation was accelerated. A more robust hypothesis is that there has been a long-term trend towards aridity or variability in, at least, the northern part of Australia, and such a pattern is evident in physical as well as biological proxy data. The proposed changes in marine isotope signatures in the Coral Sea may be indicative of the development of the West Pacific Warm Pool, perhaps a threshold response to the movement of Australia into the Southeast Asian region and constriction of the Indonesian Gateway between the Pacific and Indian Oceans. Although an increase rather than decrease in precipitation might be expected by the rise in sea surface temperatures, any accompanying development in the ENSO system would have increased climatic variability and resulted in the frequent drought conditions required for effective biomass burning. A more direct influence of higher sea surface temperatures could be the expansion of mangrove vegetation that seems to have been a general regional feature of the late Quaternary.

Although there are no dramatic changes in overall rainforest distribution within the South China Sea region, the suggestion by Sun *et al.* (2003) that the climate may have become more seasonal within the last 350 kyr could be significant, if the variability was interannual instead of, or in addition to, being seasonal. This would be consistent with a broad regional ENSO signal.

One important feature of the history of most, if not all, of the region is that conditions during the latter part of the last glacial period to the present day were distinctive, and are limited in the degree they can be applied to an understanding of extreme glacial and interglacial conditions or the nature of abrupt climate changes, in general. Assessment of the extent of savanna expansion during glacial periods is particularly problematic and critical to the understanding of mammal, including hominid, migrations into and establishments within the region. The separation of climatic and human influences is clearly important for patterns of change that relate to moisture variables, but the suggestion that the cooler-adapted communities were extensive during the last glacial period suggests that temperature variation also needs to be taken into consideration when comparison is made of glacial–interglacial cycles.

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